Researches upon Brown Coals and Lignites. Part I.—*Heat Treatment at Temperatures below* 400° *C. as a Possible Method for Enhancing their Fuel Values.*

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Introduction.

Coals may be conveniently divided into four principal genera, namely (A) Sub-bituminous, including brown coals and lignites, (B) Bituminous, (C) Semi-bituminous, and (D) Anthracitic, of which the first is, generally speaking, of more recent origin than the other three. According to the Report issued by the International Geological Congress in 1913, of the world's estimated total coal reserves (7,397,553 million tons), about 40·5 per cent. are sub-bituminous and lignitic, 52·75 are bituminous, and the remaining 6·75 per cent. are anthracitic. It is evident, therefore, that a large proportion of the world's coal reserves are of the immature sub-bituminous type whose economic values as fuels have hitherto been regarded as much inferior to those of the geologically older bituminous and anthracitic groups.

The world-wide economic dislocations caused by the War, and notably the great increase in the cost of winning and transporting the more valuable bituminous and anthracitic coals, have so profoundly affected the fuel situation generally, that the relative standing of the sub-bituminous brown coals and lignites has been of late much enhanced. Indeed, it may be truly said to-day that in many countries, including several of our Overseas Dominions, the question of how best to utilise their potential lignite coal resources has become one of first-rate importance. Already in Australia, Canada, and the United States, the matter is being vigorously investigated under Government auspices or direction as one of pressing economic necessity. It may, therefore, be assumed that if scientific research could disclose how the inferior brown coals and lignites may be "up-graded" by a simple process into something approximating to the more valuable black coals, it might not only add to our knowledge of coal formation in past ages, but also would powerfully aid the solution of a present-day economic problem of world-wide importance. In this paper will be described the results of some experiments which have been recently carried out with this end in view.

Lignites and brown coals comprise a great variety of principally tertiary coals which may be regarded as intermediate between peat and bituminous coals. In their natural state they vary considerably in character and chemical composition according to the degree of transformation of the original vegetable *débris* (chiefly lignin) from which they were derived. From this point of view, further investigation may ultimately show that they include as many sub-groups as are known to exist among the geologically older bituminous (*i.e.*, black) coals. Unfortunately, however, our present chemical knowledge of the brown coals is too limited to admit of anything better than some such provisional classification of them, according to their external appearances, as the following:—

(A) Woody or Fibrous Brown Coals, such as retain a distinct ligneous structure;

(B) Amorphous or Earthy Brown Coals, which are devoid of any organic structure;

(C) Common or Brown Lignites, which are dark brown in colour and have a distinct laminated structure and fracture; and

(D) Black Lignites, which are nearly black in colour and have a conchoidal fracture.

It is also possible that such a classification gives some index of the extent to which the "coal formation" has proceeded.

These sub-bituminous coals are further characterised as a genus by the following common features, which, taken together, differentiate them from the older bituminous coals, namely, in that (i) they naturally contain a large amount of water (*e.g.*, always more than 10, and sometimes even as much as 50, per cent.); (ii) on losing the same by "air-drying" they usually disintegrate, either crumbling to powder or developing well-marked laminar cracks; (iii) they are absolutely devoid of any coking properties; and (iv) in the "dry ashless" state they contain much more oxygen and less carbon than do any of the bituminous coals. Thus a "dry ashless" lignite will usually contain less than 70 per cent. of carbon and more than 20 per cent. of oxygen.

Owing to their low carbon and high oxygen contents, sub-bituminous coals have, even in the dry state, much lower calorific values than any of the older types; and when their high water-contents in the raw state are considered, together with the fact that they usually disintegrate on being dried by any of the ordinary methods, it will be readily understood that the problem of their transportation for any long distance has always presented formidable difficulties.

In the raw state they are at best a low-grade fuel, burning with a very long and smoky flame. And, owing to so much heat being required to evaporate their natural water-content, they do not give a very hot or radiating fire, which in boiler practice is so essential to rapid heat transmission and efficient working. Against their obvious inferiority as fuels to bituminous coals may be set the consideration that some of them are capable of yielding on carbonisation at low temperatures a variety of valuable by-products including volatile hydrocarbons, fuel and lubricating oils, solid paraffins, etc. These latter possibilities will be more fully dealt with in a subsequent paper, but meanwhile attention may be drawn to them.

As already mentioned, most of the brown coals and lignites are geologically of tertiary age, although some of them are undoubtedly cretaceous. Indeed, it has been proposed to discriminate between what have been termed true brown coals or lignites, which are chiefly tertiary, and sub-bituminous coals proper, which are chiefly cretaceous. This is, however, more of a geological than a chemical question, which, lying as it does outside the ambit of the author's purpose, does not immediately concern him.

Tertiary brown coals and lignites are chiefly found (i) in what may be termed the "Pacific borderlands," *e.g.*, in North-west America, Japan, Australia, New Zealand, and the East Indies; (ii) in regions adjacent to, or in continuation with, the Gulf of Mexico; and (iii) in regions north of the Mediterranean, including the Central European Plain.

Economically speaking, the most important of the known tertiary lignite areas in the world are probably those of Victoria (Australia), Saskatchewan (Canada), North Dakota (U.S.A.), and Germany, although valuable deposits occur, and in some cases are being worked, in Japan, India, Burma, Malaya, and New Zealand, as well as other parts of our Overseas Dominions. Cretaceous sub-bituminous coals chiefly occur in the western parts of Canada (Alberta) and the United States.

A. *An Experimental Investigation of Morwell Brown Coal.*

The present research originated in a request, made to the author in October, 1916, by the Agent-General for the Government of Victoria (Australia), for certain assistance in connection with examining the nature of the tars and oils obtained on carbonising at a low temperature the celebrated Morwell brown coal deposits in the Gippsland district, about 97 miles from Melbourne. These Victorian brown-coal deposits are of tertiary origin, and, according to the Report of the Government Advisory Committee, they consist of "a matrix of earthy brown coal with sporadic inclusions of lignite. . . . The matrix consists of pollen grains, spore cases, and decomposed vegetable matter. . . . The coal varies in colour between yellowish brown and black, but it always pulverises to brown powder."* The Morwell deposits, which lie quite near the surface, are of exceptional thickness, and represent an enormous store of potential energy whose economic importance to the State of Victoria can scarcely be overrated. Thus, in the Report of the International Geological Congress upon the Coal Resources of the World, it is stated that "the thickness of the Gippsland deposits is shown in a bore-hole put down near Morwell which disclosed no fewer than seven beds of brown coal. Three of these proved to be of phenomenal thickness, without parallel elsewhere."* A summary of the seams cut was as follows:—

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* 'Report of Victorian Advisory Committee on Brown Coal,' 1917.

Depth from surface to top of seam.		Thickness of coal.	
ft.	ins.	ft.	ins.
66	2	29	8
167	6	25	8
202	2	23	0
251	6	227	10
482	4	265	6
818	4	166	1
995	2	43	8
Total coal		781	5

Unfortunately, however, these Morwell brown coals usually contain in the raw state between 45 and 55 per cent. of water, and therefore it is difficult to burn them efficiently under boilers. Nevertheless, in the year 1917, the Advisory Committee appointed by the Victorian Government to investigate the possibilities of generating electric power from them on a large scale, reported† that, notwithstanding their low-grade character, it would be more economical to generate electric power for the City of Melbourne from them than from New South Wales coals. About that time also it was officially estimated that the cost of producing raw Morwell coal at the mines would not exceed 2*s.* 9*d.* per ton. The estimated cost of delivering Morwell coal in Melbourne was then 7*s.* 8*d.* per ton, against about 20*s.* for black coal imported from Newcastle (New South Wales). And as the result of developments that are now taking place, it is anticipated that, in a few years hence, not only will the City of Melbourne derive the whole of its electric power from Morwell coal, but that the Victorian State Railways will also be worked electrically by energy from the same deposits.

A representative sample of this Morwell coal was, in 1917, forwarded to the author for scientific investigation from the Victorian Ministry of Mines, through the courtesy of Sir Peter MacBride, the Agent-General for Victoria in London. It was consigned in six sealed tin cases, and was found to be a typical earthy brown coal. Its moisture-content, as it reached his laboratory, was 48 per cent. This water was all rapidly eliminated when the coal was maintained either (*a*) at 105° C. in a current of nitrogen, or (*b*) at the room temperature in a vacuum over strong sulphuric acid. The dry coal yielded 55·3 per cent. of volatile matter when carbonised at 900° C. out of contact with air, and its ultimate composition was found on analysis to be as follows:—

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* 'Coal Resources of the World,' vol. 1, p. 42.

† 'State of Victoria Report of the Advisory Committee on Brown Coal,' Melbourne, 1917.

	Dry coal.	Dry ashless coal.
	per cent.	per cent.
Carbon	62·50	65·10
Hydrogen	4·85	5·00
Nitrogen	0·45	0·45
Sulphur	0·20	0·20
Oxygen	28·00	29·25
Ash	4·00	—
	100·00	100·00

Gross calorific value of the dry coal = 5600 K.C.Us. per kilogramme (or 10,080 B.T.Us. per lb.).

Heat Treatment of the Dry Coal.—On investigating the behaviour of the thoroughly dried coal when further heated, out of contact with air, in a special form of apparatus which permitted accurate control of temperature and the measurement of the amounts of either liquid or gaseous products evolved, the following significant observations were made, which subsequent research has proved to be characteristic of brown coals and lignites generally. It was found that, beginning at as low a temperature as 130° C., but principally between 250° and 375°, a chemical change occurred, which was characterised by the elimination of both steam and carbon dioxide from the coal substance, without any appearance of condensable oils or more than a quite negligible amount of gaseous hydrocarbons. Thus, in a typical experiment, when the temperature of 100 parts by weight of the dry coal was slowly raised to, and then maintained at, 375° C. until no further change occurred (the whole duration of the operation averaging about two hours), there were eliminated 5·5 parts of water and 6·6 parts by weight of gas (= 1427 cubic feet of gas per ton of dry coal), which latter contained:—

$$H_2S = 1{\cdot}5,\quad CO_2 = 88{\cdot}5,\quad CO = 4{\cdot}1,\quad CH_4 = 1{\cdot}1,\quad \text{and}\quad N_2 = 4{\cdot}8 \text{ per cent.}$$

The reason for not continuing the heating beyond 375° C. was that such degree marked the limit to which the treatment could be pushed without the coal losing either hydrocarbon oils or gases. And—inasmuch as subsequent investigation showed that for any particular lignite there is a similar temperature limit (usually between 300° and 400° C.) up to which the dry "coal substance" in like manner loses large quantities of both carbon dioxide and steam as the result of a chemical condensation affecting mainly (if not entirely) its cellulosic or humic constituents, without either appreciably changing its hydrocarbon-yielding constituents or materially diminishing its potential energy as a fuel,—it is proposed to term such temperature the "practicable upgrading limit" for that particular lignite. This phrase is suggested because the temperature in question marks the practicable limit beyond which the concentration of potential energy in the dried fuel, consequent upon the said chemical condensation, cannot usefully be pushed without incurring appreciable thermal loss.

How far such concentration of potential heat units is practicable in the case of the Morwell coal investigated may be deduced from the following considerations, namely:—

(1) That the 87·6 parts of "residual coal" obtained after treating 100 parts by weight of the dry coal in the foregoing experiments was found on analysis to contain:—

	Per cent.
Carbon	68·5
Hydrogen	4·9
Nitrogen	0·5
Sulphur	0·3
Oxygen	21·2
Ash	4·6
	100·0

(2) That its gross calorific value was:—

6,360 K.C.Us. per kilogramme (or 11,450 B.T.Us. per pound);

(3) And, therefore, that the chemical and thermal balances for the experiments were somewhat as follows:—

	100 parts of the original dry coal containing	yielded	87·6 parts of residual coal containing	Loss.
	parts.		parts.	parts.
Carbon	62·50		60·00	2·50
Hydrogen	4·85		4·30	0·55
Oxygen	28·00		18·55	9·45
K.C.Us.	560,000		558,000	2,000

It will thus be seen that the original dry coal had lost altogether 13·4 per cent. of its weight (principally as carbon dioxide and steam), but had retained practically the whole of its potential heating power. The loss in question had amounted to approximately one-third of the oxygen, one-tenth of the hydrogen, but only one-thirtieth of the carbon originally present in the coal substance. Leaving the bearing of such a result upon the chemistry of coal formation to be discussed at some future time, some of its possible economic applications may now be indicated.

Some Economic Considerations.—It being obvious from the foregoing experiments that the brown coal in question could be considerably "up-graded" by a simple heat treatment at temperatures well below 400° C. in the manner described, further investigations were made with a view to determining whether the heat required first to dry and then to "up-grade" the raw coal could be supplied in a large power station or boiler installation at the expense of a portion of the sensible heat in the products of combustion from the treated fuel, assuming them to leave the boiler system at a temperature of not less than 400° C. These investigations have shown that such combustion products do carry away from the boiler several times more heat than would suffice for the purpose in view. Moreover, laboratory experiments have indicated that it would not be necessary, for the completion of the "up-grading" process, to maintain the dry coal at 375° C. for more than about forty-five minutes, and also that the aforesaid products of combustion could be safely employed for the purpose provided that they contain more than 10 per cent. of carbon dioxide. Large-scale trials of the scheme are accordingly now in contemplation, with a view to testing its applicability to the Morwell deposits.

The advantages accruing from a successful issue of such trials would be (*a*) that the raw fuel would be dried and "up-graded" *in situ* by means of heat which would otherwise be lost up the chimney, or, in other words, that the incoming raw coal would act as an "economiser" in the boiler system; and (*b*) that the "up-graded" fuel would subsequently give a much hotter and more radiant fire in the boiler furnace, thereby increasing the steam output and thermal efficiency of the system.

B. *Investigation of other Typical Lignites.*

As it seemed important to ascertain whether (and if so, then how far) the behaviour of Morwell brown coal under the aforesaid heat treatment is characteristic of sub-bituminous coals as a class, steps were taken to obtain representative samples of lignites of widely different origins. The author was fortunate in securing several such typical consignments, from which the following were selected as best answering the purpose in view:—

(1) A series of Italian woody lignites (Class A) from the San Giovanni Valdarno District.

(2) Two Italian lignites (Class C) from Umbria.

(3) A series of four Canadian lignites (Class C/D) from the Province of Saskatchewan.

(4) A Burmese lignite (Class D).

Details of the investigation of all these samples will now be given.

(1) *Italian Lignites from the Valdarno District.*—There are several lignite deposits in the northern parts of Italy (chiefly in Tuscany and Umbria) of which those of San Giovanni Valdarno are economically the most important. In pre-war days the Italian production of lignite amounted to about 550,000 tons per annum, of which about 75 per cent. were of Tuscan, and about 20 per cent. of Umbrian origin. The principal Italian deposits occur in the mountain chain separating the valley of the Arno from that of Chianti, and are commonly known as the Valdarno deposits.

According to the Report issued by the International Geological Congress in 1913, these Valdarno deposits occur in the lower Pliocene measures, and in the raw state they usually contain between 40 and 50 per cent. of water. They have a very woody appearance and fibrous structure, so much so that they can usually be sawn into pieces without crumbling. In colour they are dark brown. The author was fortunate in securing through the Italian Military Mission in London one representative sample, and subsequently he obtained some others privately.

As received at his laboratory, they contained between 25 and 40 per cent. of water; the volatile matter in the "dry ashless" coals varied between 55 and 60 per cent. An ultimate analysis of one of the dried samples (No. 1) was made, with the following results, from which it will be seen that (as might be expected from its "woody" character) the coal substance contained decidedly less carbon but more oxygen than the Morwell brown coal.

On investigating the behaviour of three different consignments of Valdarno lignites when submitted in a dry state to the heat treatment in question, it was found that the highest temperature to which they could be raised without losing hydrocarbon or volatile oily vapours varied between 285° and 310° C., instead of the 375° previously employed in the case of the Morwell coal. Possibly this difference may be attributed to the more woody (*i.e.*, resinous) character of the Valdarno coals. In other respects their behaviour was very similar to that of the Morwell coal, namely, that up to the experimental temperature limit in question, water and carbon dioxide were freely eliminated from the dried coal substance without any material loss in potential calorific value. It should, however, be noted that the gases eliminated from the coal

Valdarno No. 1.

	Dry coal.	Dry ashless coal substance.
	per cent.	per cent.
Carbon	54·90	60·30
Hydrogen	4·90	5·40
Nitrogen	0·60	0·65
Sulphur	1·20	1·30
Oxygen	29·50	32·35
Ash	8·90	—
	100·00	100·00
Percentage volatile matter yielded at 900° C.	52·6	57·8

Gross calorific value of the dry coal = 5390 K.C.Us. per kilogramme (=9710 B.T.Us. per lb.).

(1) Results of Experiments upon Italian Lignites.

	Valdarno (Tuscany).			Umbria.	
	1.	2.	3.	Fontivecchi.	Poggio Mirteto.
Per cent. moisture in raw coal	39·1	25·4	27·4	21·9	28·6
Data relating to dry coal—					
Percentage volatiles yielded at 900° C.	52·6	52·3	53·5	48·5	53·5
Percentage ash	8·9	6·0	5·7	16·3	9·6
Gross calorific value (K.C.Us. per kgrm.)	5390	5490	5690	4595	5630
Experimental temperature limit (C°.)	300°	310°	285°	320°	300°
Results of heat treatment of the dry coal—					
Percentage loss in weight	8·0	9·7	7·5	10·4	9·9
	Gas H_2O	Gas H_2O	Gas H_2O	Gas H_2O	Gas H_2O
	4·0 4·0	4·0 5·7	2·8 4·7	4·7 5·7	3·2 6·7
Cubic feet of gas at N.P.T. per ton	808	786	550	908	624
Percentage composition of the gas—					
CO_2	74·0	85·2	79·6	83·7	82·9
CO	21·0	10·5	12·7	10·9	6·6
C_2H_6	1·3	0·3	2·7	1·0	1·5
N_2	3·7	4·0	5·0	4·4	9·0
Gross calorific value of residual fuel (K.C.Us. per kgrm.)	5830	5840	6010	5060	6020
K.C.Us. in residue from 1 kgrm. dry coal	5365	5265	5505	4425	5445

during the heat treatment contained appreciably more carbon monoxide than did those previously obtained in the experiments with Morwell coal. The general character of the experimental results may be judged from Table (1) on p. 244.

The gross calorific value of the carbonaceous residue obtained from the No. 1 sample was:—

5830 K.C.Us. per kilogramme (= 10,500 B.T.Us. per lb.),

and it had the following ultimate composition:—

	As obtained.	On "ashless" residue.
	per cent.	per cent.
Carbon	58·9	65·2
Hydrogen	4·7	5·2
Nitrogen and sulphur	2·0	2·2
Oxygen	24·7	27·4
Ash	9·7	—
	100·0	100·0

The following balance relating to the heat treatment of the consignment in question has been deduced from the experimental data.

	100 parts of the original dry coal containing	yielded	92 parts of residual coal containing	Loss.
	parts.		parts.	parts.
Carbon	54·9		54·2	0·7
Hydrogen	4·9		4·3	0·6
Oxygen	29·5		22·7	6·8
K.C.Us.	539,000		536,500	2,500

It will thus be seen that, as the result of the heat treatment of the particular sample, practically 99 per cent. of the original potential energy of the coal had been concentrated in the ninety-two parts of the residual fuel. From the thermal point of view, the results with the other Valdarno samples were perhaps not quite so favourable; in these cases there was, on the average, a concentration of about 97 per cent. of the original potential energy of the dried coal in the ninety parts of the residual fuel obtained.

(2) *Laminated Italian Lignites from Umbria.*—Two consignments of Umbrian lignites from Fontivecchi and Poggio Mirteto, respectively, were next investigated. They were quite different in both colour and structural

character from the Valdarno samples, having a dark greyish-brown appearance, and laminated structure with "slaty" cleavage. Umbrian lignites are usually considered to be of Pliocene origin, and, in pre-war days, between 100,000 and 150,000 tons per annum were produced for fuel purposes. As received at the author's laboratory, the raw coals contained between 20 and 30 per cent. of water.

The following data for the ultimate chemical composition of the dry ashless Fontivecchi sample show that it approximated closely to that of the Valdarno coals:—

	Dry coal.	Dry ashless coal substance.
	per cent.	per cent.
Carbon	51·3	61·3
Hydrogen	4·2	5·0
Nitrogen and sulphur	1·0	1·2
Oxygen	27·2	32·5
Ash	16·3	—
	100·0	100·0

Gross calorific value = 4595 K.C.Us. per kilogramme (8280 B.T.Us. per lb.).

Further particulars concerning the character of the coals, and their behaviour when subjected to the heat treatment in question, are tabulated on p. 244; it will be seen that the temperature to which they could be raised without losing hydrocarbons was between 300° C. and 320° C. Up to such temperature limit, the dried coals lost on the average about 10 per cent. of their weight (again chiefly as carbon dioxide and water), and about 97 per cent. of their potential calorific value was concentrated in the carbonaceous residue. The ultimate composition of this residue was as follows:—

Composition of the Residue from Fontivecchi Coal.

	As obtained.	On "ashless" residue.
	per cent.	per cent.
Carbon	58·0	71·3
Hydrogen	3·6	4·4
Nitrogen and sulphur	1·0	1·2
Oxygen	18·7	23·1
Ash	18·7	—
	100·0	100·0

Gross calorific value = 5060 K.C.Us. per kilogramme (or 9120 B.T.Us. per lb.).

The balance for the heat treatment was therefore as follows:—

	100 parts of the original dry coal containing	yielded	87·4 parts of residual coal containing	Loss.
	parts.		parts.	parts.
Carbon	51·3		50·7	0·6
Hydrogen	4·2		3·1	1·1
Oxygen	27·2		16·3	10·9
K.C.Us.	459,500		442,500	17,000

(3) *Canadian lignites.*—Through the courtesy of the Lignite Research Board of Canada, four typical samples of lignites from the Province of Saskatchewan were sent to the author for detailed investigation during the summer of 1919. Each of them weighed between 40 lb. and 50 lb., and was shipped over in a sealed tin, marked so as to show its origin, as follows:—

(1) Estevan Coal and Brick Co., Estevan.
(2) Saskatchewan Coal, Brick, and Power Co., Shand.
(3) Bienfait Mine, Bienfait.
(4) Western Dominion Collieries, Taylorton.

All the four samples had a dull brown or slaty black colour, and a conchoidal fracture. They were quite devoid of any "woody" structure, and, although typical tertiary lignites of a character intermediate between Classes C and D, they were certainly more mature coals than any of those dealt with in the preceding section of this paper.

As received at South Kensington, the samples contained between 32 and 38 per cent. of water. When thoroughly dried, they yielded on the average about 44 per cent. of volatile matter at 900° C., or the equivalent of about 48 per cent. on the dry ashless coal substance. Their ultimate compositions and calorific values (for the dry coal) were as follows:—

	1.	2.	3.	4.
	per cent.	per cent.	per cent.	per cent.
Carbon	63·8	62·7	64·5	61·6
Hydrogen	4·2	4·7	4·3	4·2
Sulphur	0·6	0·8	0·7	0·9
Nitrogen	0·6	0·8	0·7	1·0
Oxygen	24·7	22·5	20·5	21·1
Ash	6·1	8·5	9·3	11·2
Calorific values, K.C.Us. per kilogramme	5885	5980	5920	5650

In order, however, that a proper comparison may be made with the corresponding data for the Morwell coal (q.v.), it is necessary to exclude from the calculation the ash contents, and to consider only the following figures for the dry "coal substance" itself:—

	1.	2.	3.	4.
	per cent.	per cent.	per cent.	per cent.
Carbon	68·0	68·5	71·1	69·4
Hydrogen	4·4	5·1	4·7	4·7
Oxygen	26·2	24·6	22·6	23·7

The average potential energy of the Saskatchewan "coal substance" would be 6330 K.C.Us. per kilogramme, as compared with only 5830 for that of the less mature Morwell coal.

The experimental heat treatment of the dry coals, the results of which are set forth in the Table (2) below, showed that, up to a temperature limit varying between 320° C. and 360° C. (but on the average of about 350°), they lost about 8·5 per cent. in weight by the expulsion of steam and oxides

(2) Results of Experiments upon Canadian Lignites.

Description of sample.	1. Estevan.	2. Shand.	3. Bienfait.	4. Taylorton.
Per cent. moisture in raw coal as received	37·8	37·1	35·8	31·8
Data relating to dry coal—				
Percentage volatiles yielded at 900° C.	41·9	48·7	41·5	44·8
Percentage ash	6·1	8·5	9·2	11·2
Gross calorific value (K.C.Us. per kgrm.)	5885	5980	5920	5650
Experimental temperature limit (C.)	330°	360°	320°	340°
Results of heat treatment of the dry coal—				
Percentage loss in weight	9·8	8·5	7·2	8·2
	Gas H_2O	Gas H_2O	Gas H_2O	Gas H_2O
	4·0 5·8	4·3 4·2	4·5 2·7	4·7 3·5
Cubic feet of gas at N.T.P. per ton	810	880	890	940
Percentage composition of the gas				
CO_2	71·6	68·3	76·9	75·7
CO	25·9	30·6	19·9	23·0
N_2	2·5	1·1	3·2	1·3
Gross calorific value of residual fuel (K.C.Us. per kgrm.)	6380	6465	6230	6130
K.C.Us. in residue from 1 kgrm. dry coal	5700	5785	5780	5490

of carbon; but, whilst carbon dioxide was still the predominating gaseous product, it was associated with a much larger proportion of the monoxide than had been found in the gases similarly obtained from any of the less mature coals previously investigated. Thus, for example, the ratio CO_2/CO in the gases from these Saskatchewan samples varied between 2·5 and 3·5, as compared with 22·0 for the Morwell coal, and between 5·0 and 12·0 for all (except one) of the Italian samples. No hydrocarbon at all was evolved during the heat treatment up to the experimental temperature limit. The carbonaceous residues obtained had the following ultimate compositions and calorific values, namely:—

Residual Fuels from Samples.

	1.	2.	3.	4.
	per cent.	per cent.	per cent.	per cent.
Carbon	68·0	68·4	67·5	67·3
Hydrogen	4·4	4·3	4·0	3·5
Nitrogen and sulphur	1·4	1·8	1·6	2·1
Oxygen	19·3	15·8	16·8	14·4
Ash	6·9	9·7	10·1	12·7
K.C.Us. per kilogramme	6380	6465	6230	6130

The results obtained with the four different samples were so nearly alike that the following composite balance-sheet for the experimental treatment may be regarded as substantially correct for the series as a whole:—

	100 parts of the original dry coal containing	yielded	91 parts of residual coal containing	Loss.
	parts.		parts.	parts.
Carbon	63·25		62·0	1·25
Hydrogen	4·35		3·7	0·65
Oxygen	22·20		15·6	6·60
K.C.Us.	586,000		576,000	10,000

Thus it is seen that the dry coals lost by the heat treatment about one-fiftieth part of their original carbon (as CO_2 and CO in the ratio of about 3 to 1 by volume), between one-sixth and one-seventh part of their original hydrogen (as steam), and as much as 30 per cent. of their original oxygen (the total loss in weight amounting to one-twelfth of that taken), but retained more than 98 per cent. of their potential energy in the residual fuel.

(4) *Investigation of a Burmese Lignite.*—The following details concerning the heat treatment of a Burmese lignite investigated may be cited as showing the extent to which the fuel value of a mature lignite of Class D may be improved. The sample in question had a shiny-black colour and a well-marked conchoidal fracture.

As received, it contained about 10 per cent. of moisture; the dry coal contained 4·1 per cent. of ash, and yielded at 900° C. 45·8 per cent. of volatile matter, equivalent to 47·7 per cent. on the "dry ashless" coal.

It was found that the practical limit to which the heat treatment could be pushed was 320° C., at which temperature hydrocarbon oils first appeared. Up to this limit the dried fuel suffered a loss of 7 per cent. in weight, of which 4·3 was due to gases containing 83·2 per cent. of carbon dioxide, 11·4 per cent. of carbon monoxide, and 5·4 per cent. of nitrogen.

The following was the balance-sheet of the experimental treatment:—

	100 parts of the original dry coal containing	yielded	93 parts of residual coal containing	Loss.
	parts.		parts.	parts.
Carbon	63·6		62·3	1·3
Hydrogen	4·8		4·1	0·7
Oxygen	26·1		20·4	5·7
K.C.Us.	612,000		604,000	8,000

C. *Summary and Conclusions.*

Having now investigated representative samples, obtained from widely different localities, of the four principal classes of tertiary brown coals and lignites, and having found no material difference between their behaviour on heat treatment within the range of temperature in question, it seems highly probable that such behaviour is common to lignites as a whole. Accordingly, it may be concluded:—

(1) that there is for each particular lignite a certain definite temperature limit (usually between 300° and 400° C.) up to which it may be heated in the dry state so as to effect a considerable chemical condensation in its cellulosic or humic constituents, with simultaneous expulsion therefrom of steam and carbon dioxide, together with a small but variable proportion of carbonic oxide;

(2) that the said chemical condensation is unaccompanied, within the temperature range in question, by any other change productive of either hydrogen or hydrocarbons;

(3) that the consequent loss in weight experienced by the "dry ashless"

coal substance up to the temperature limit in question may amount to anything between 8 and 15 per cent. of its original weight;

(4) that such loss in weight occurs principally at the expense of the oxygen-content of the dry coal, which is diminished by between one-quarter and one-third of its original value;

(5) that, substantially, the whole of the potential energy of the fuel may be correspondingly concentrated by suitable heat treatment (within the prescribed temperature limit) in the resulting carbonaceous residue, which may therefore be burnt with greater calorific intensity than the original coal; and

(6) that, accordingly, such treatment constitutes a possible means of "up-grading" brown coals and lignites generally, thus improving their fuel values.

It is not proposed, at this stage of the inquiry, to discuss the possible bearing of the experimental results on the question of coal formation, though obviously they may prove to be of considerable interest in such connection, as showing how the cellulosic or humic part of a consolidated deposit of vegetable *débris* would probably behave if subjected to the quite moderate degree of heat contemplated in the paper. At temperatures between 300° C. and 400° C., the chemical condensation in question rapidly reaches its end-point for that temperature; as a matter of fact, it would usually be completed within one or, at the most, two hours. At lower temperatures, it would, of course, proceed more slowly, but it would tend to the same end-point.

Before, however, entering upon the discussion of such larger questions, it is proposed to carry out further experiments, with the object of ascertaining more precisely (*a*) the influence of pressure, as well as temperature, upon the speed and course of the chemical condensation in question, and (*b*) the cause of the variation in the proportion of carbonic oxide evolved. These and other aspects of the question are now being investigated under the author's direction at South Kensington.

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